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Improved model for correcting the ionospheric impact on bending angle in radio occultation measurements

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Abstract

Operational numerical weather prediction (NWP) systems routinely assimilate radio occultation measurements made with the Global Positioning System (GPS-RO) [*Marquardt et al.*, 2003]. Furthermore, investigations have indicated that GPS-RO could have an important role in monitoring the stratospheric climate. One issue that may affect the quality of climate monitoring applications is the impact of residual ionospheric errors on the stratospheric retrievals.

[*Kursinski et al.*, 1997] provides an outline of the GPS-RO technique. The GPS satellites transmit on two L-band channels (L1, L2) at $f_1 = 1575.42$ MHz and $f_2 = 1227.60$ MHz. Assuming spherical symmetry, the bending angle of the ray between the GPS satellite and a receiver in LEO is:

$$\alpha_{Li}(a) = -2a \int_{r_t}^{\infty} \frac{dn_i/dr}{n_i\sqrt{(n_i r)^2 - a^2}} dr \qquad \text{Equation 1}$$

where $i = 1,2$ depending on the frequency; a is the impact parameter; r_t is the tangent height of the ray path; and n_i is the refractive index. To a first order approximation, the refractive index comprises terms dependent on the neutral atmosphere refractivity (N_n), the ionospheric electron density (n_e), and the frequency (f) squared:

$$n_i \cong 1 + 10^{-6} N_n(r) - 40.3 \frac{n_e(r)}{f_i^2} \qquad \text{Equation 2}$$

Therefore, the measured L1 and L2 bending angles are different from each other, and both contain neutral and ionospheric components. The standard approach taken in operational RO processing centres is to estimate a corrected neutral atmosphere bending angle (α_c) using the approach described by [*Vorob'ev and Krasil'nikova*, 1994]:

$$\alpha_c(a) = \alpha_{L1}(a) + \frac{f_2^2}{f_1^2 - f_2^2}[\alpha_{L1}(a) - \alpha_{L2}(a)] \qquad \text{Equation 3}$$

where the L1 and L2 bending angles (α_{L1} and α_{L2} respectively) are interpolated to a common impact parameter. One benefit of this approach is that it is based on the standard parameters estimated by the retrieval system and does not require *a priori* information about the ionosphere. One downside is that a systematic bending angle error remains. [*Vorob'ev and Krasil'nikova*, 1994] show that these errors increase as a function of the electron density squared, integrated over the vertical profile.

[*Healy and Culverwell*, 2015] have proposed a modification to the standard ionospheric correction of the form:

$$\alpha_c(a) = \alpha_{L1}(a) + \frac{f_2^2}{f_1^2 - f_2^2}[\alpha_{L1}(a) - \alpha_{L2}(a)] + \kappa(a)(\alpha_{L1}(a) - \alpha_{L2}(a))^2 \qquad \text{Equation 4}$$

where the kappa term compensates for the systematic residual error in the standard approach. They investigate the sensitivity of kappa using a range of analytic vertical ionospheric profiles and conclude that kappa falls in the range of 10 to 20 rad^{-1}. [*Danzer et al.*, 2015] explored the validity of the new bending angle correction by ray-tracing through 3D ionospheric model. Unfortunately, high levels of noise in the simulated bending-angles at mid to high latitudes prevented thorough latitudinal investigation of the correction's performance.

In this paper a monthly median ionospheric model (NeQuick, [*Nava et al.*, 2008]) will be used to investigate the spatial, temporal and solar flux dependence of kappa. For example, *Figure 1* shows the global distribution of kappa derived from NeQuick for 1200 UT, June and at 60 km altitude. A simple model for kappa will be proposed. This will not rely on ionospheric knowledge, but can be used to produce un-biased corrected bending angles.

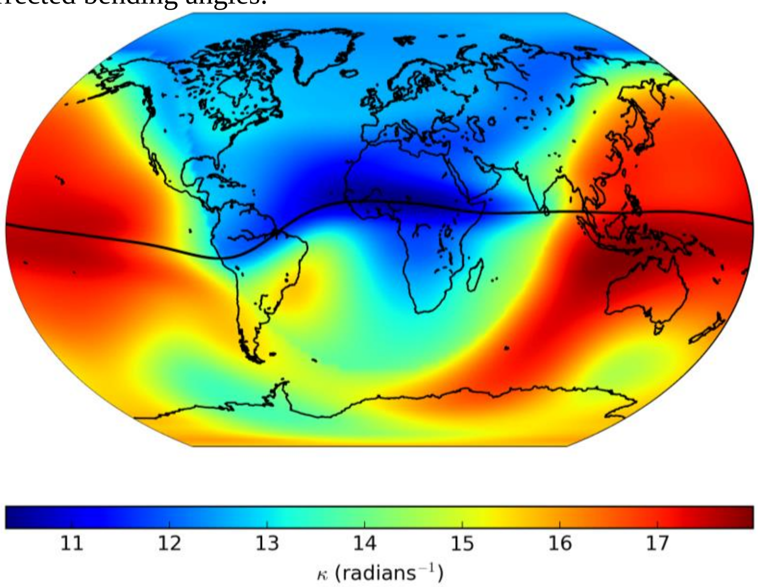

Figure 1. Example map of Kappa for 12 UT at 60 km generated using NeQuick.

References:

Danzer, J., S. B. Healy, and I. D. Culverwell (2015), A simulation study with a new residual ionospheric error model for GPS radio occultation climatologies, *Atmos. Meas. Tech*, *8*, 3395–3404, doi:10.5194/amt-8-3395-2015.

Healy, S. B., and I. D. Culverwell (2015), A modification to the standard ionospheric correction method used in GPS radio occultation, *Atmos. Meas. Tech.*, *8*(8), 3385–3393, doi:10.5194/amt-8-3385-2015.

Kursinski, E. R., G. A. Hajj, J. T. Schofield, R. P. Linfield, and K. R. Hardy (1997), Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System, *J. Geophys. Res.*, *102*(D19), 23429–23465.

Marquardt, C., J. R. Eyre, S. B. Healy, A. Jupp, and D. Offiler (2003), *Use of GPS radio occultation data in meteorological services*, UK Met Office.

Nava, B., P. Coisson, and S. Radicella (2008), A new version of the neQuick ionosphere electron density model, *J. Atmos. Solar-Terr. Phys.*, doi:10.1016/j.jatsp.2008.01.015.

Vorob'ev, V. V, and T. G. Krasil'nikova (1994), Estimation of the accuracy of the atmospheric refractive index recovery from the NAVSTAR system, *USSR Phys. Atmos. Ocean (Eng. Trans.), 29*(5), 602–609.